Environmental Research 158 (2017) 610–615

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Effectiveness of table top water pitcher filters to remove arsenic from drinking water

Roxanna Barnaby[a], Amanda Liefeld[a], Brian P. Jackson[b], Thomas H. Hampton[a], Bruce A. Stanton[a,*]

[a] Department of Microbiology and Immunology, The Geisel School of Medicine at Dartmouth, Hanover, NH 03755, United States
[b] Department of Earth Sciences, Dartmouth College, Hanover, NH 03755, United States

ARTICLE INFO

Keywords:
Arsenic
Water filter
Filtration
Water quality
Drinking water

ABSTRACT

Arsenic contamination of drinking water is a serious threat to the health of hundreds of millions of people worldwide. In the United States ~3 million individuals drink well water that contains arsenic levels above the Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 µg/L. Several technologies are available to remove arsenic from well water including anion exchange, adsorptive media and reverse osmosis. In addition, bottled water is an alternative to drinking well water contaminated with arsenic. However, there are several drawbacks associated with these approaches including relatively high cost and, in the case of bottled water, the generation of plastic waste. In this study, we tested the ability of five tabletop water pitcher filters to remove arsenic from drinking water. We report that only one tabletop water pitcher filter tested, ZeroWater®, reduced the arsenic concentration, both As^{3+} and As^{5+}, from 1000 µg/L to < 3 µg/L, well below the MCL. Moreover, the amount of total dissolved solids or competing ions did not affect the ability of the ZeroWater® filter to remove arsenic below the MCL. Thus, the ZeroWater® pitcher filter is a cost effective and short-term solution to remove arsenic from drinking water and its use reduces plastic waste associated with bottled water.

1. Introduction

Arsenic contamination of drinking water is a serious threat to the health of hundreds of millions of people worldwide (Carlin et al., 2016; Flanagan et al., 2015a; Smith et al., 2016; Zheng and Ayotte, 2015). In the United States (U.S.), for example, forty-three million people use private wells and the United States Geological Survey estimates that ~3 million people in the U.S. drink private well water that contains arsenic levels above the World Health Organization (WHO) standard and U.S. EPA MCL of 10 µg/L, which was established in 2001 (Zheng and Ayotte, 2015). However, arsenic levels in private wells are unregulated. It is up to the homeowner to test to determine if there is arsenic in the water and to take appropriate action to reduce the arsenic concentration (Carlin et al., 2016; Spayd et al., 2015; Zheng and Ayotte, 2015).

A major emphasis of the Dartmouth Superfund Research Program (http://www.dartmouth.edu/~toxmetal/ and http://www.dartmouth.edu/~arsenicandyou/), as well as Superfund Research Programs at Columbia University (http://superfund.ciesin.columbia.edu/), University of Arizona at Tucson (https://superfund.arizona.edu/https://superfund.arizona.edu/), University of California at Berkley (http://superfund.berkeley.edu/), University of California at San Diego (http://superfund.ucsd.edu/), University of Washington (http://deohs.washington.edu/srp/) and the University of North Carolina at Chapel Hill (http://sph.unc.edu/superfund-pages/srp/), as well as private, government and state agencies (for example, New Hampshire Department of environmental Services (http://des.nh.gov/organization/divisions/water/dwgb/capacity/arsenic.htm)), is to encourage individuals who drink water from private wells to test their well water for arsenic every three years. If well water arsenic is above 10 µg/L it is recommended that the consumer change to bottled water immediately, contact the local or state health department, and install either a whole house water treatment system (i.e., point of entry, POE) or a point of use (POU) filtration system, which treats the water at a single tap, to reduce the arsenic concentration to as close to zero as possible ([http://www.dartmouth.edu/~arsenicandyou/index.html]) (Flanagan et al., 2015a, Spayd et al., 2015, Stanton et al., 2015). The choice of a treatment system for arsenic depends on several features of

Abbreviations: U.S. EPA, United States Environmental Protection Agency; POU, point of use; POE, point of entry; ICP-MS, inductively coupled plasma mass spectrometry: SEM, standard error of the mean. PFOA, perfluorooctanoic acid; PDBE, polybrominated diphenyl ethers; BPA, bisphenol A; NIST, National Institute of Standards and Technology; WQA, Water Quality Association; , ANSI, American National Standards Institute; USD, United States Dollars

* Correspondence to: Microbiology and Immunology, The Geisel School of Medicine at Dartmouth, 615 Remsen Building, North College Street, Hanover, NH 03755, USA.
E-mail addresses: Roxanna.L.Barnaby@dartmouth.edu (R. Barnaby), Amanda.E.Liefeld@dartmouth.edu (A. Liefeld), Brian.P.Jackson@dartmouth.edu (B.P. Jackson), Thomas.H.Hampton@dartmouth.edu (T.H. Hampton), Bruce.A.Stanton@dartmouth.edu (B.A. Stanton).

http://dx.doi.org/10.1016/j.envres.2017.07.018
Received 22 February 2017; Received in revised form 7 July 2017; Accepted 8 July 2017
0013-9351/

water chemistry including, but not limited to, other contaminants, pH, manganese and iron concentrations, and the arsenic oxidation state and concentration (Sarkar and Paul, 2016). One relatively inexpensive approach to eliminate exposure to arsenic in well water is to use bottled water, which has been estimated to cost several hundred dollars per year (Flanagan et al., 2015a; Smith et al., 2016). Other approaches to remove arsenic from well water include POU treatment systems that can cost from \$300 USD up to several thousand dollars to install plus yearly maintenance costs (~\$100/yr.), and POE treatment systems that cost \$2000 to \$3000 USD to install plus yearly maintenance costs (~\$200 to \$300 USD/yr.) (Flanagan et al., 2015b, Smith et al., 2016). In addition to cost, which is known to be a barrier to remediation, there are other limitations to the use of bottled water and reverse osmosis systems, including the generation of plastic waste and backwash waste water disposal, respectively (Flanagan et al., 2015b; Smith et al., 2016; Spayd et al., 2015).

In this study, we tested the effectiveness of five inexpensive (~\$20 to \$35 USD for the filtration unit and ~\$10 to \$15 USD for replacement filters) and readily available tabletop water pitcher filters to remove arsenic from drinking water. The impetus for this study was to identify a robust, low cost and easy to use system to reduce arsenic in drinking water obtained from private wells. In a recent review of arsenic and environmental health it was noted that a key research need is to improve remediation strategies (Carlin et al., 2016). We report that only one tabletop water pitcher filter tested, ZeroWater®, reduced arsenic, both As^{3+} and As^{5+} in spiked municipal water, from 100 μg/L to below 1 μg/L. Moreover, the ZeroWater® water pitcher filter also reduced the arsenic concentration from 1000 μg/L to 2.6 μg/L, a value below the U.S. EPA MCL of 10 μg/L. In addition, the ZeroWater® filter also reduced arsenic in well water samples obtained in New Hampshire from 42 μg/L to below detection. The amount of total dissolved solids did not affect the ability of the ZeroWater® water pitcher to remove arsenic below the MCL.

2. Materials and methods

2.1. Tabletop water pitcher filters

Five commercially available tabletop water pitcher filtration units, including two of the most popular brands in the U.S., Pur® (model# PPT700W) and Brita® (model# OB36/OB03) were purchased from local merchants. In addition, tabletop water pitcher filtration units by ZeroWater® (model# ZD-013-D), Great Value® (Wal-Mart-model# QP6-OS) and HDX® (Home Depot-model# QP8-07) were also tested. For each brand three different lots of filters were tested.

2.2. Arsenic solutions

To make influent solutions containing arsenic, As^{+5} and As^{+3} stock (1000 mg/L) were purchased from Inorganic Ventures, Christiansburg, VA. Appropriate amounts of each stock solution were added to tap water (Hanover, NH public water supply, soft water) to make solutions with a final total arsenic concentration of 10 μg/L (5 μg/L As^{+3} and 5 μg/L As^{+5}), 100 μg/L (50 μg/L As^{+3} and 50 μg/L As^{+5}), and 1000 μg/L (500 μg/L As^{+3} and 500 μg/L As^{+5}). As^{+3} and As^{+5} were added to the influent water since both arsenic species can be present in well water: the relative concentration of each depends primarily on the pH and O_2 content (Sorg et al., 2014). Arsenic concentrations of 10 μg/L and as high as 100 μg/L are not uncommon in well water in the U.S. (Spayd et al., 2015; Zheng and Ayotte, 2015). Arsenic concentrations of 1000 μg/L in well water are less common, but are observed occasionally in the U.S. as well as world-wide. A second set of influent solutions was made in moderately hard water (see below) with a final total arsenic concentration of 10 μg/L (5 μg/L As^{+3} and 5 μg/L As^{+5}) and 100 μg/L (50 μg/L As^{+3} and 50 μg/L As^{+5}). The salt composition of the soft water solution was (Na^+, 11.1 ppm; Mg^{++}, 1.28 ppm; K^+, 1.7 ppm; Ca^{++}, 8.46 ppm; and hardness as $CaCO_3$ was 26.41 mg/L)(CE, 2000). The salt composition of the moderately hard water solution was (Na^+, 16.3 ppm; Mg^{++}, 4.9 ppm; K^+, 1.7 ppm; Ca^{++}, 16.6 ppm; and hardness as $CaCO_3$ was 61.4 mg/L) (CE, 2000). A third set of arsenic solutions was made in distilled water and contained either 100 μg/L of As^{+3} or 100 μg/L of As^{+5}. Also, water samples were obtained from two wells in New Hampshire known to contain arsenic (~42 μg/L): one well was in Concord, NH and the other well was in Kensington, NH. These well water samples, although representative of samples obtained in New Hampshire (https://nh.water.usgs.gov/project/nawqa/data_gw.htm), differ significantly from other aquifers in the US and other countries that are characterized by higher levels of silica and sulfate. The concentration of As^{+3} and As^{+5}, as well as Si, P, S, and Fe, in all influent solutions was measured by ICP-MS.

2.3. ICP-MS

Arsenic concentration in the influent (i.e., raw unfiltered water) and the filter effluent (i.e., filtered water) was measured by ICP-MS (Agilent 7900 and 8800) following U.S. EPA 200.8 but using He as a collision gas. The instrument was calibrated using National Institute of Standards and Technology (NIST) traceable standards and an initial and continuing calibration verification was performed every 10 samples. Detection limit for arsenic was 0.05 μg/L.

2.4. Filtration tests

The first set of experiments was performed on the five filters described above. Briefly, ten liters of influent soft water containing arsenic was added to each filter, in 1 L increments in the following order: control (no arsenic added), 10 μg/L, 100 μg/L and 1000 μg/L. This was repeated with three lots of each filter brand, except for HDX®, which did not have lot numbers, instead three different filters were purchased from three different Home Depot locations. The second set of experiments was limited to the ZeroWater® filter because it was the only filter to reduce the arsenic concentration in all influent samples tested to a value below 10 μg/L. Since the ZeroWater® performance data sheet suggests that the filter be replaced after 15 gallons (~57 L) studies were also conducted to test the ability of the filter (three different lots) to reduce the arsenic concentration in 100 L of water, in 1 L increments, containing either 10 μg/L or 100 μg/L arsenic in soft and hard water. The third set of experiments was conducted to test the ability of the ZeroWater® filter to remove either 100 μg/L of As^{+3} or 100 μg/L of As^{+5} from distilled water. The fourth set of experiments was conducted to test the ability of the ZeroWater® filter to remove naturally occurring arsenic from water obtained from two wells in NH.

2.5. Data analysis and statistics

Graphpad Prism version 6.0 for Macintosh (Graphpad, San Diego, CA) was used to perform a statistical analysis of the data. Means were compared using a *t*-test or ANOVA followed by Tukey's test, as appropriate. $P < 0.05$ was considered significant, and all data are expressed as the mean ± SEM.

3. Results

3.1. Comparison of five tabletop pitcher filtration units

Fig. 1 presents the results of studies conducted to examine the ability of five tabletop water pitcher filtration units to reduce the arsenic concentration in the influent containing 10 μg/L. ZeroWater®, Pur®, Brita® and Great Value® reduced the arsenic concentration below 10 μg/L: however, HDX® did not reduce the arsenic concentration below 10 μg/L. Only the ZeroWater® filter reduced the arsenic concentration to less than 1 μg/L.

Next, studies were conducted to test the ability of the filters to